From Big Data to Big Control: Closing Feedback Loops around Large-scale Infrastructure Data

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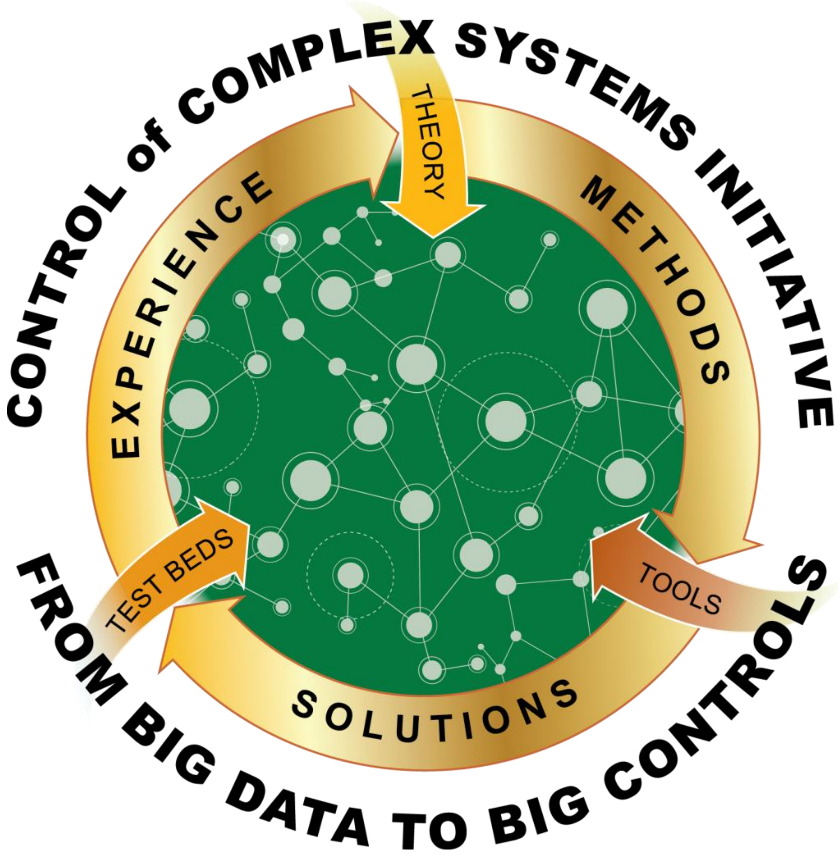
Control of Complex Systems Initiative: From Big Data to Big Controls

CCSI: A five year, multi-million dollar internal research investment to build and demonstrate development and delivery of best of class solutions for problems in the control of complex systems.

Challenges for Big Controls:

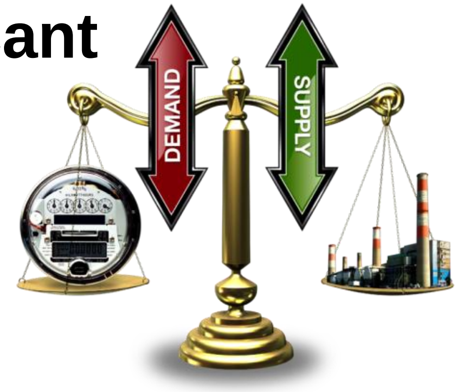
- Large numbers of sensing and/or control end points
- Multiple scales of operation usually with multiple time scales
- Node heterogeneity
- Pervasive computing/autonomous nodes



Control solutions will be:
Scalable, *deployable*, *robust*, *resilient*, and *adoptable*.

Significant Challenges Facing the Grid

The challenges facing the grid are significant and in tension with each other



- Maintain and increase reliability
- Integrate renewables & low-carbon sources
- Potential electrification of vehicle transportation
  (& other end uses as electricity becomes the preferred “fuel”)
- Increase asset utilization, reduce capacity for peak loads
- ***While keeping costs & revenues as low as possible***

Smart grid is the most promising approach to addressing these challenges simultaneously

- Much of smart grid’s promise lies in distributed assets: Demand response, distributed storage & generation, electric vehicles, smart inverters

Future Control Architecture of the Grid

Designing a novel control architecture for the power grid needs a significant number of considerations, e.g.:

- Laws of electro-physics must be observed
- Current/future stakeholder boundaries must be respected
- Architecture must be deployable in a modular, incremental fashion
- For reasons of robustness, resilience & flexibility, the control architecture must be layered
- Considering the huge number of assets, lowest layer must be a *distributed control architecture*

Transactive Controls *is a very promising approach for such a distributed control architecture*

Transactive Controls / Transactive Energy

Refers to *techniques for managing the generation, consumption or flow of electricity* within a power system, *using economic or market-based constructs*, while *respecting grid reliability constraints*.

The term "*transactive*" comes from considering that *decisions are made based on a value*. These decisions may be analogous to, or literally, economic transactions.

Transactive Energy Workshop Proceedings 2012, prepared by the GridWise® Architecture Council, March 2012, PNNL-SA-90082 (http://www.gridwiseac.org/historical/tew2012/tew2012.aspx)

What Problems or Issues is Transactive Control and Coordination Designed to Address?

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Principal Challenges Addressed by TC2

Principal Challenge	Approach
▶ Centralized optimization is unworkable ■ *for such large numbers of controllable assets, e.g. ~10^9 for full demand response participation*	▶ Distributed approach with self-organizing, self-optimizing properties of market-like constructs
▶ Interoperability	▶ Simple information protocol, common between all nodes at all levels of system: *quantity, price or value, & time*
▶ Privacy & security ■ *due to sensitivity of the data required by centralized techniques*	▶ Minimizes risks & sensitivities by limiting content of data exchange to simple transactions
▶ Scalability	▶ Self-similar at all scales in the grid ▶ Common paradigm for control & communication among nodes of all types ▶ Ratio of parent to child nodes limited to ~10^3

Principal Challenges Addressed by TC2 (cont.)

Principal Challenge	Approach
▶ Level playing field for all assets of all types: ■ *existing infrastructure & new distributed assets*	▶ Market-like construct provides equal opportunity for all assets ▶ Selects lowest cost, most willing assets to "get the job done"
▶ Maintain customer autonomy ■ *"Act locally but think globally …"*	▶ Incentive-based construct maintains free will ■ *customers & 3rd-parties fully control their assets* ■ *yet collaborate (<u>and get paid for it</u>)*
▶ Achieving multiple objectives with assets essential for them to be cost effective	▶ Allows (but does not require) distribution utility to act as natural aggregator ■ *address local constraints while representing the resource to the bulk grid*
▶ Stability & controllability	▶ Feedback provides predictable, smooth, stable response from distributed assets ▶ Creates what is effectively closed loop control needed by grid operators

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PNNL Transactive Energy Approach: *Transactive Control & Coordination (TC2)*

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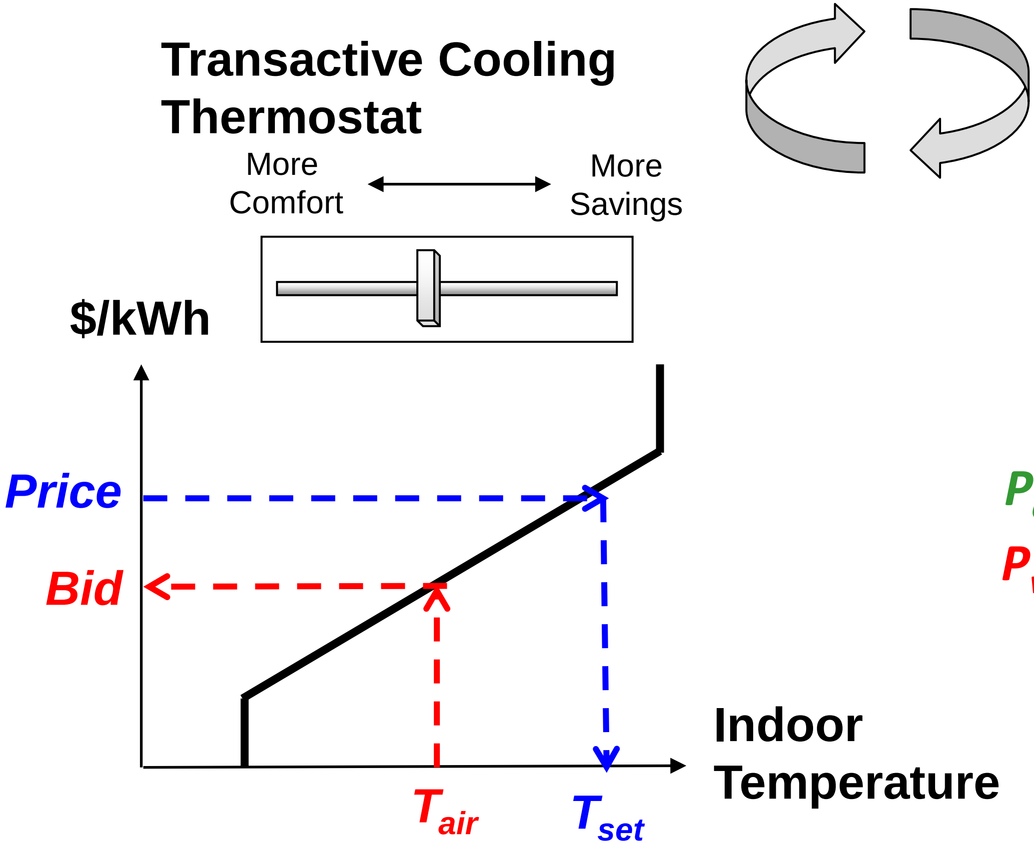
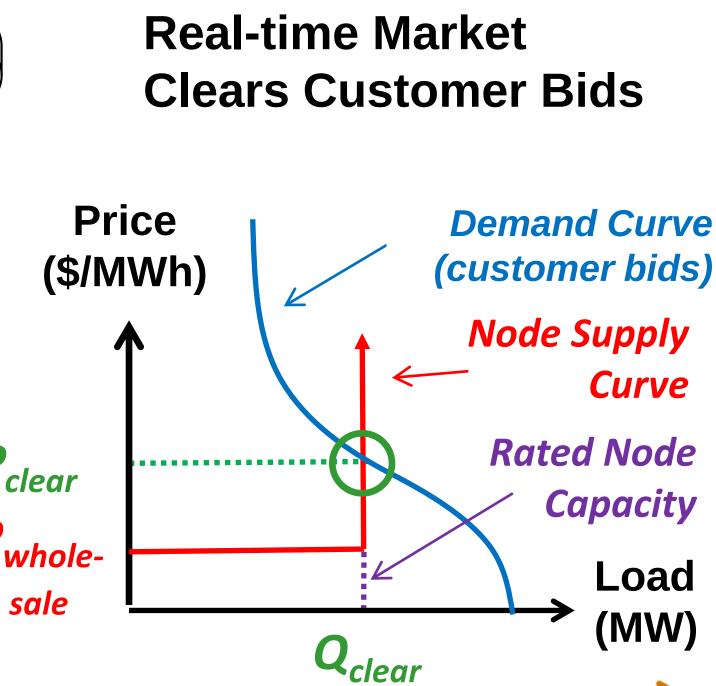
Transactive Control from Interaction of Price Discovery & Customer Bidding Algorithms

Precise, stable control of congested grid nodes derived from customer price-responsive bidding algorithm interacting with price discovery mechanism (e.g., a market)





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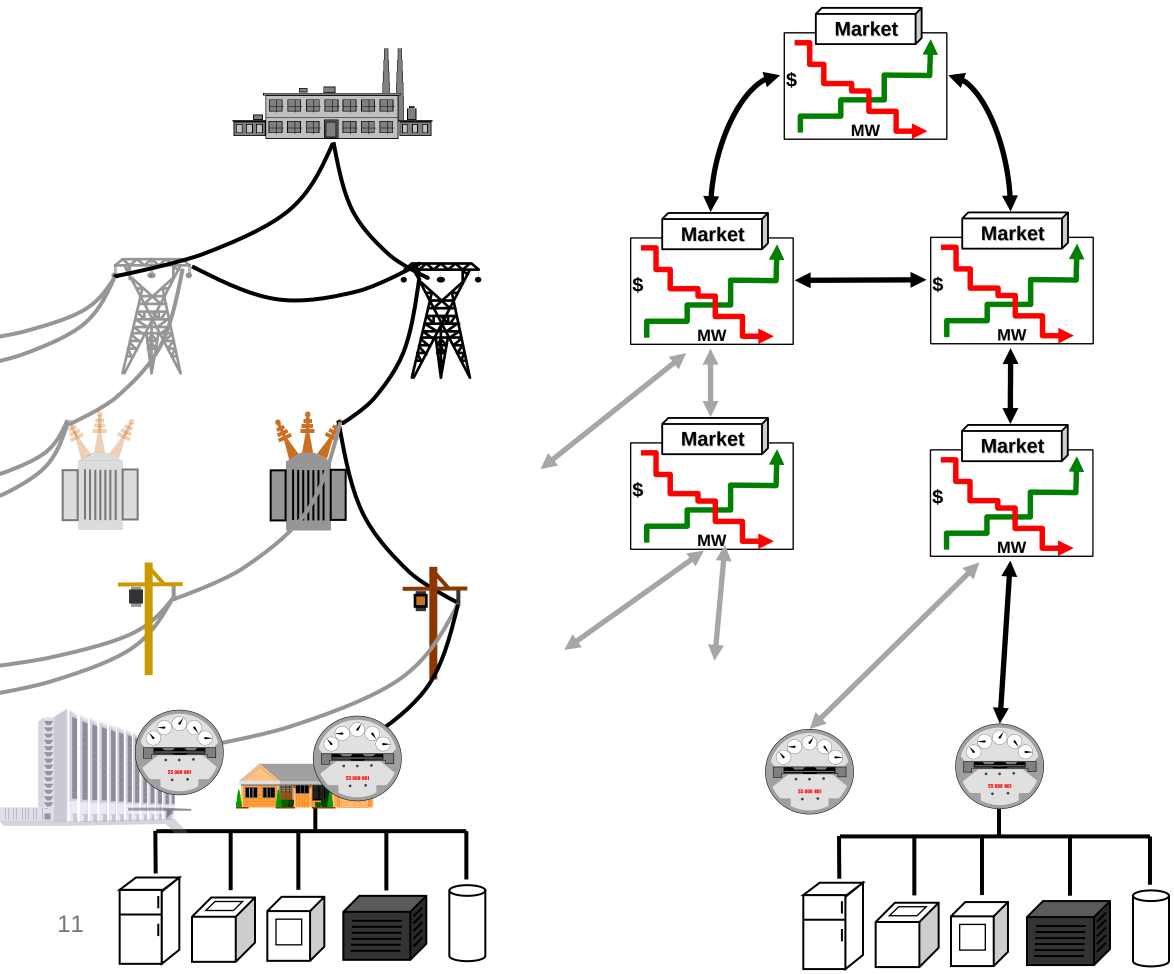
Hierarchical Network of Transactive Nodes Parallels the Grid Infrastructure

Node: point in the grid where flow of power needs to be managed



Node Functionality:

- "Contract" for power it needs from the nodes supplying it
- "Offer" power to the nodes it supplies
- Resolve price (or cost) & quantity through a price discovery process
  - market clearing, for example
- Implement internal price-responsive controls

Properties of Transactive Nodes

- Use <u>local conditions</u> & <u>global information</u> to make control decisions for its own operation
- Indicate their response to the network node(s) serving them
  - to an *incentive signal* from the node(s) serving them
  - as a *feedback signal* forecasting their projected net flow of electricity (production, delivery, or consumption)
- Setting incentive signal for nodes serves to obtain precise response from them, based on their feedback signals
- <u>Responsiveness</u> is voluntary (set by the node owner)
- <u>Response</u> is typically automated (and reflected in the feedback signal)

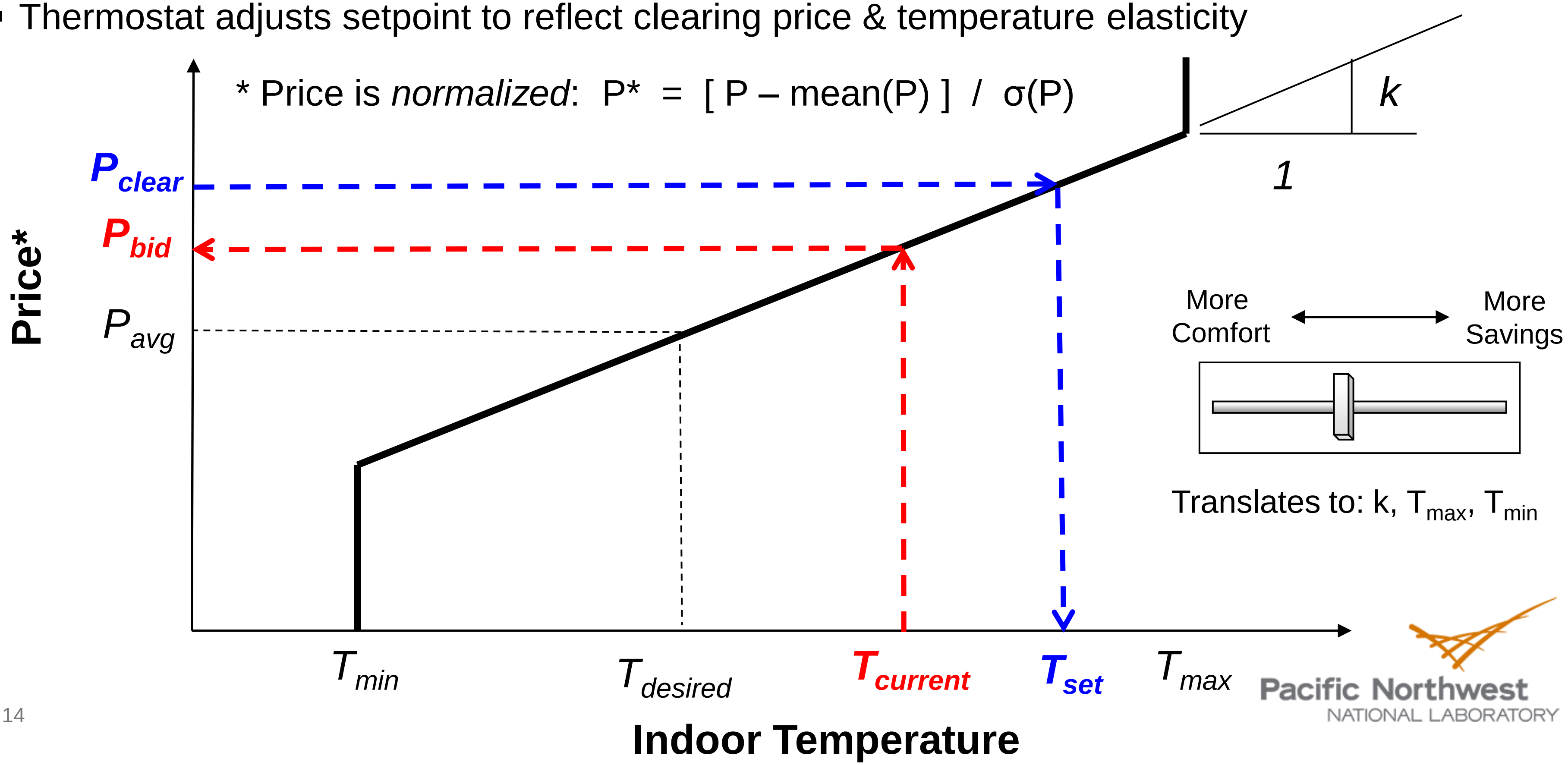
Links All Values/Benefits in Multi-Objective Control

Long-term objective for TC2 is to simultaneously achieve combined benefits

- Reduce peak loads (minimize new capacity, maximize asset utilization) – generation, transmission, & distribution
- Minimize wholesale prices/production costs
- Reduce transmission congestion costs
- Provide stabilizing services on dynamically-constrained transmission lines to free up capacity for renewables
- Provide ancillary services, ramping, & balancing (especially in light of renewables)
- Managing distribution voltages in light of rapid fluctuations in rooftop solar PV system output

Transactive Cooling Thermostat Generates Demand Bid based on Customer Settings

- User's *comfort/savings* setting implies limits around normal setpoint ($T_{desired}$), *temp. elasticity* (*k*)
- Current temperature used to generate bid price at which AC will "run"
- AMI history can be used to estimate bid quantity (AC power)
- Market sorts bids & quantities into demand curve, clears market returns clearing price
- Thermostat adjusts setpoint to reflect clearing price & temperature elasticity



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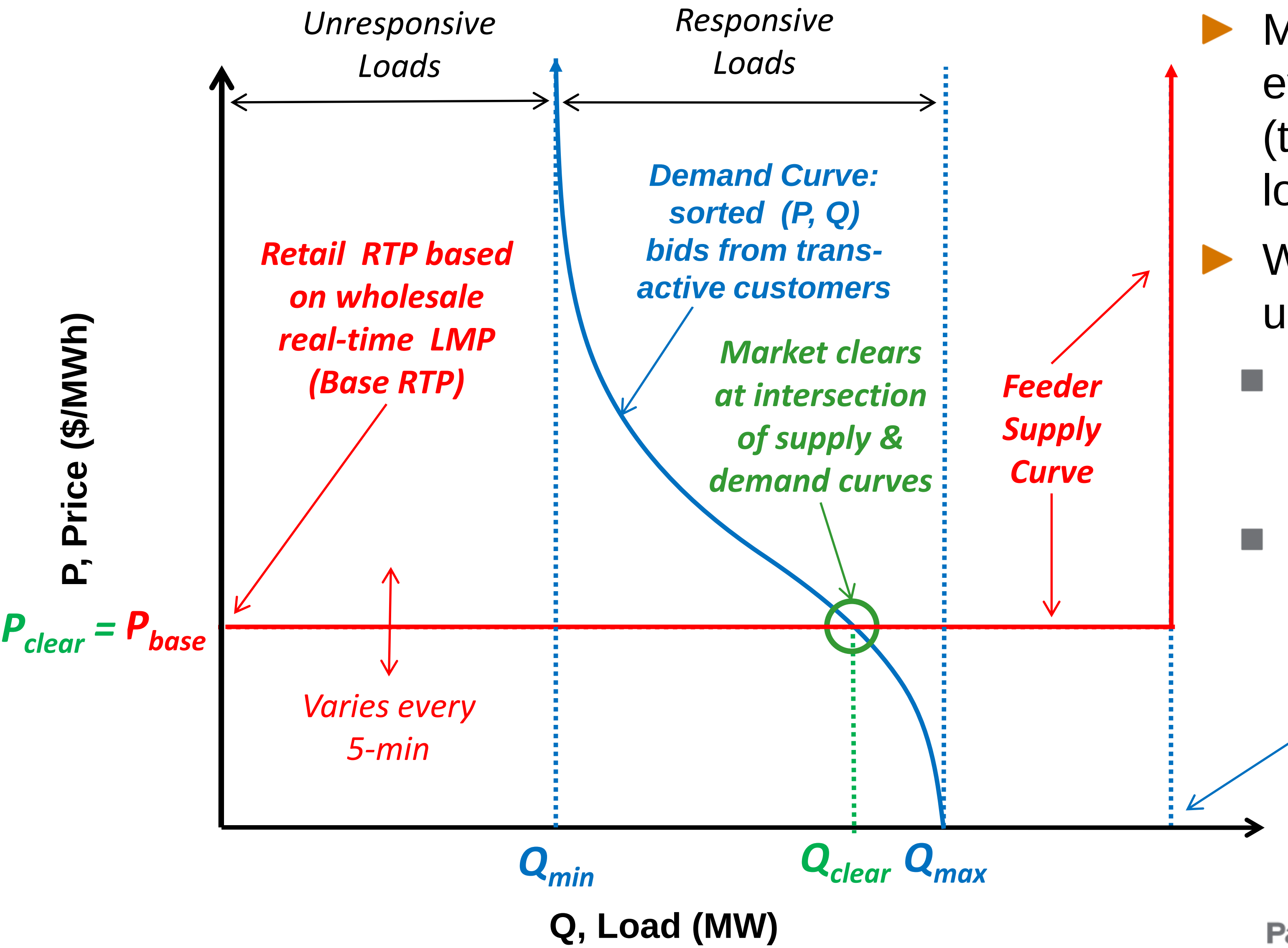
RTP Double Auction Market – *Uncongested*



- Market clears every 5-min (to ~match AC load cycle)
- When uncongested:
  - Quantity (Q_{clear}) varies with demand curve
  - Price (P_{clear}) is constant, equal to *Base RTP*

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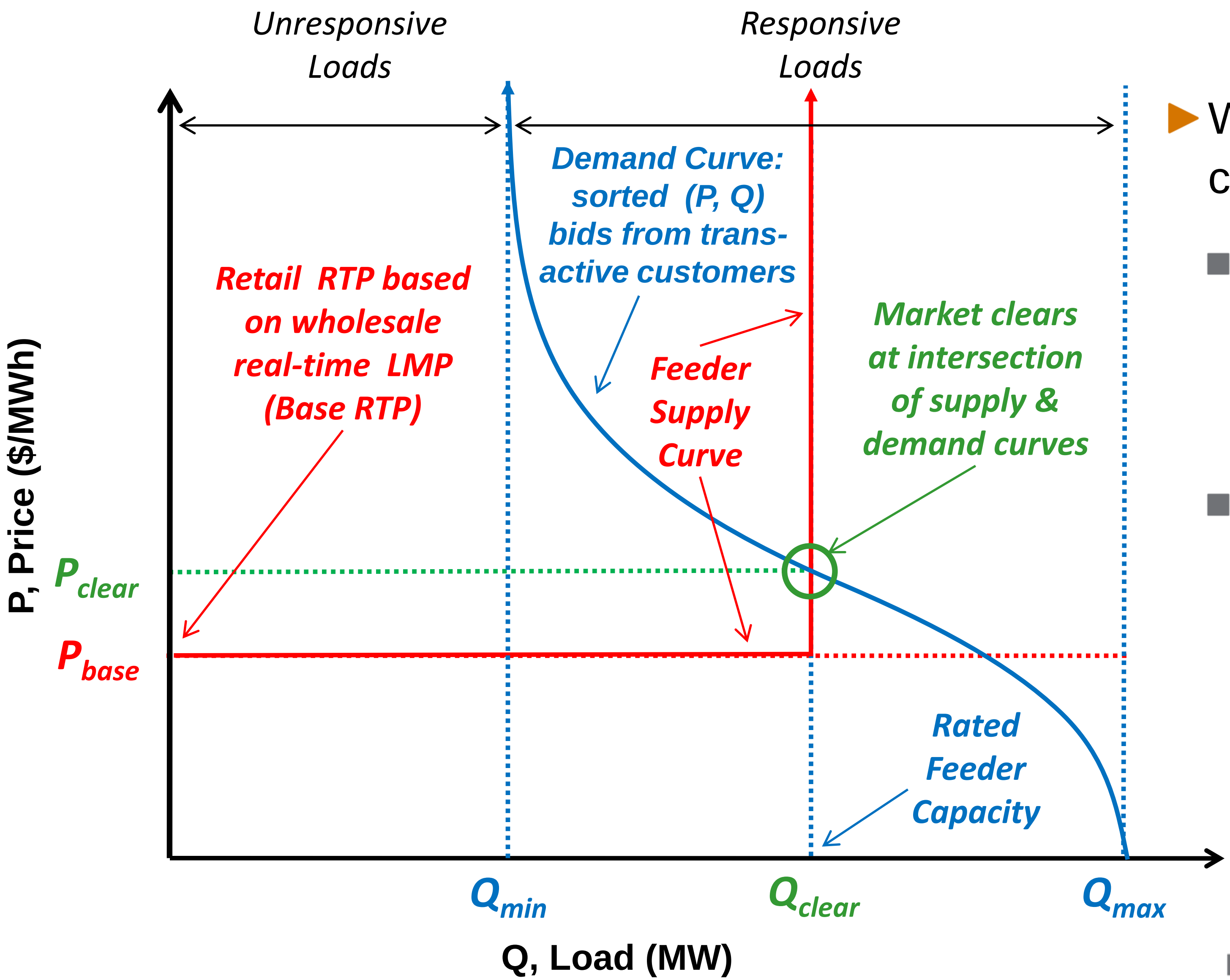
RTP Double Auction Market – *Congested*



- When constrained:
  - Quantity (Q_{clear}) is <u>constant</u> at rated feeder capacity
  - Price (P_{clear}) <u>varies</u> to keep load at rated capacity

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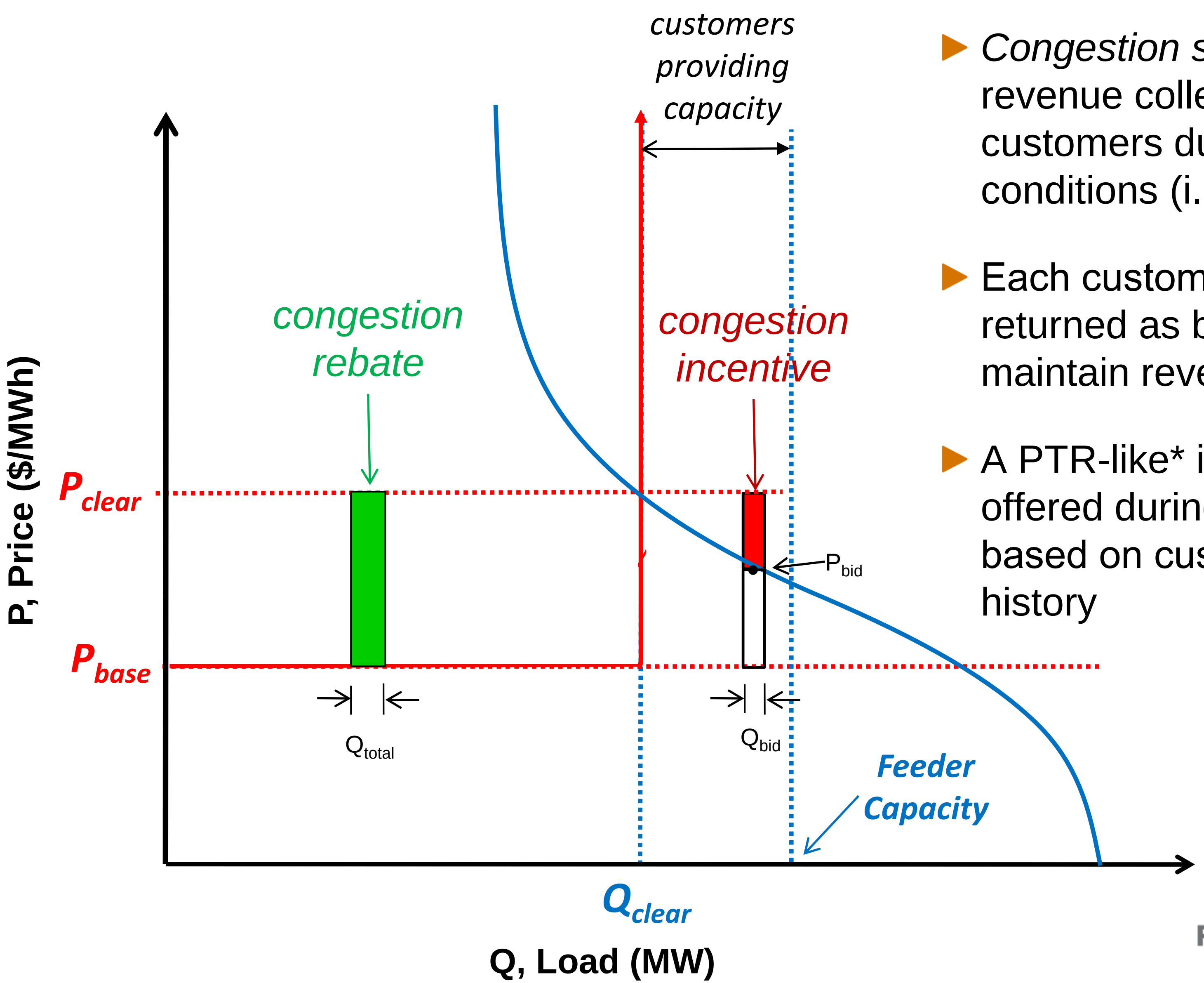
What about the Congestion Surplus?



- *Congestion surplus* is extra revenue collected from customers during constrained conditions (i.e. $P_{clear} > P_{base}$)
- Each customer's surplus returned as billing rebate to maintain revenue neutrality
- A PTR-like* incentive is also offered during congestion, based on customer's bid history

* peak time rebate

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Fully Engaging Demand: What We've Learned from the Olympic Peninsula Demonstration

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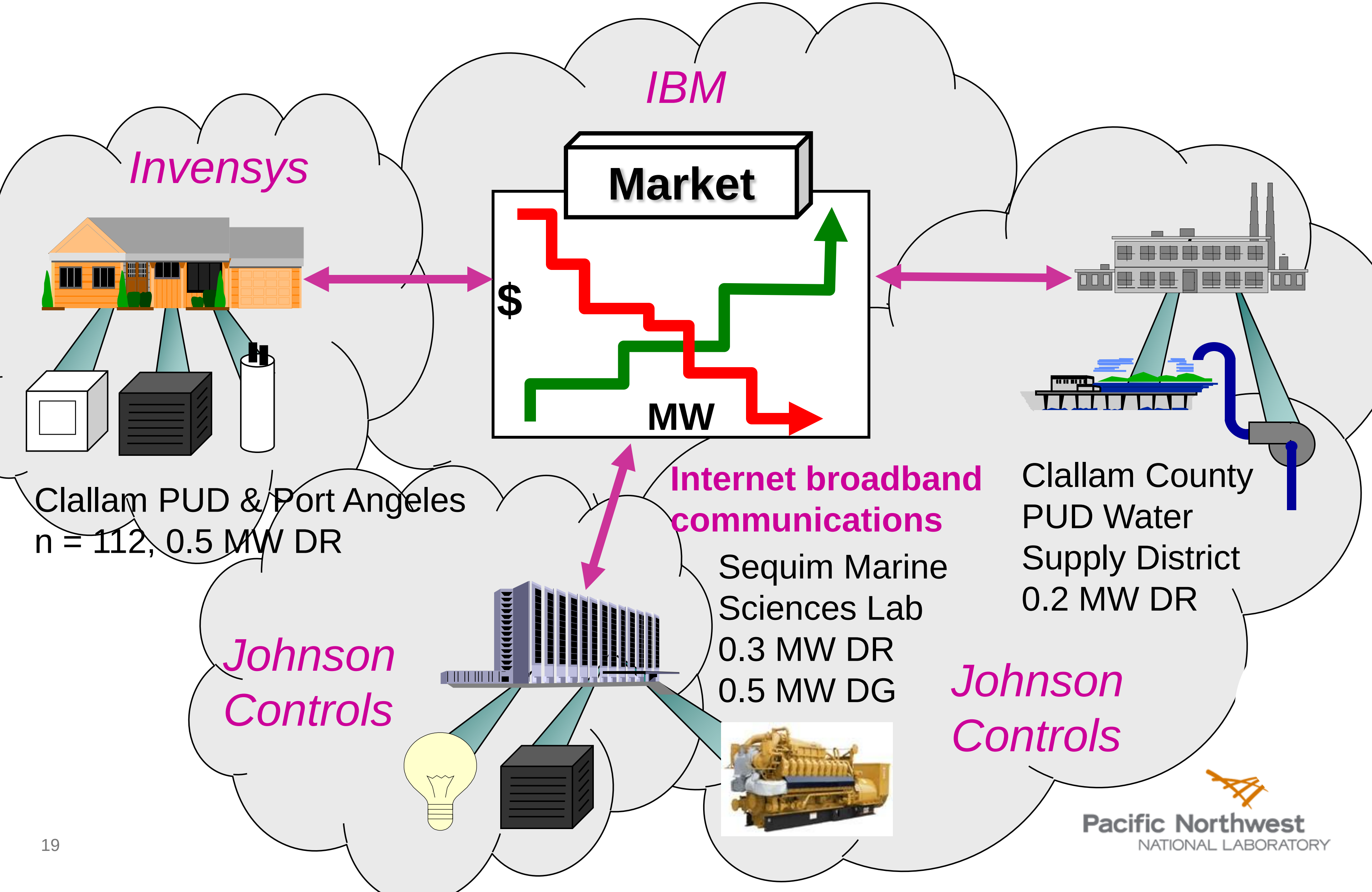
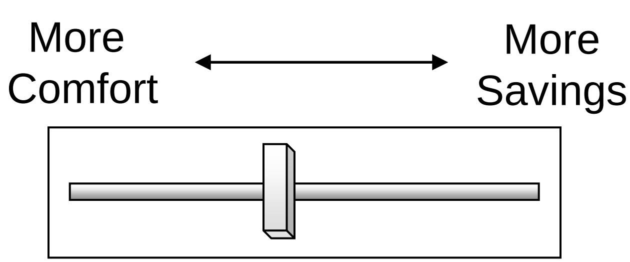
Olympic Peninsula Demonstration



Olympic Peninsula Demo: Key Findings (1)

Customers can be recruited, retained, and will respond to *dynamic pricing* schemes **<u>if they are offered</u>**:

- Opportunity for significant savings (~10% was suggested)
- A “no-lose” proposition compared to a fixed rate
- Control over how much they choose to respond, with which end uses, and a 24-hour override
  - prevents fatigue: reduced participation if called upon too often
- Technology that automates their desired level of response
- A simple, intuitive, semantic interface to automate their response



Translates to control parameters:

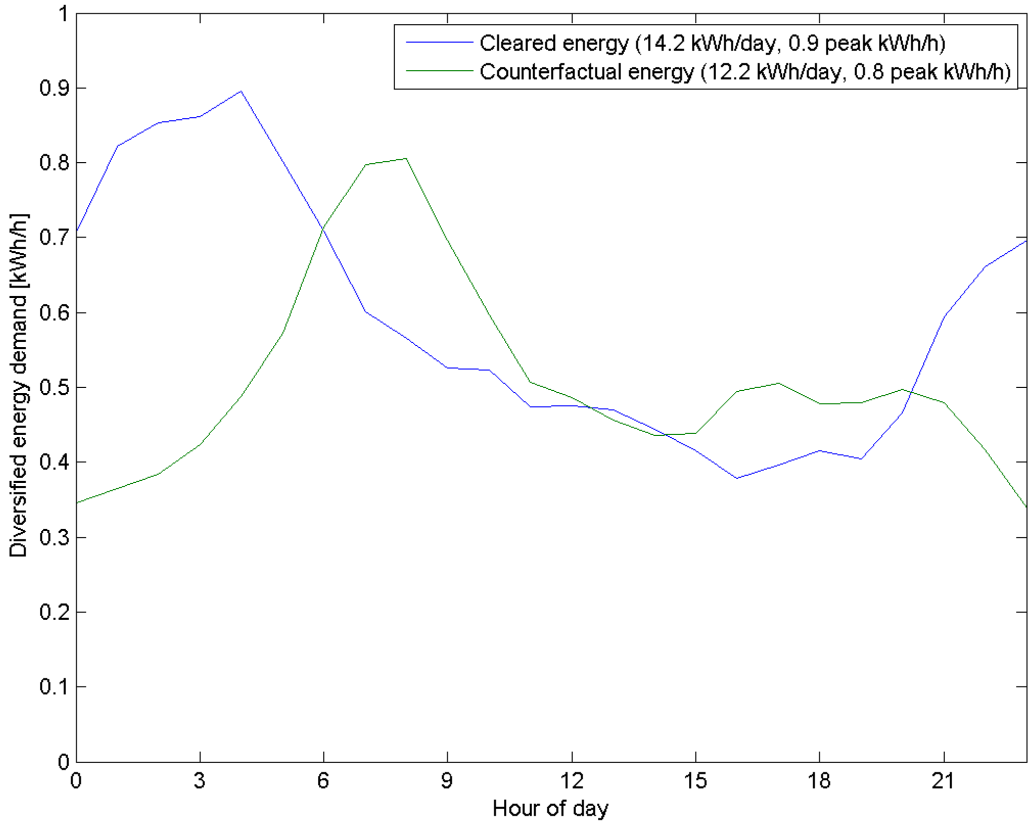
K, T_{max}, T_{min} (see *Virtual Thermostat*)

Olympic Peninsula Demo: Key Findings (2)

Significant demand response was obtained:

- 15% reduction of peak load
- Up to 50% reduction in total load for several days in a row during shoulder periods
- Response to wholesale prices + transmission congestion + <u>distribution congestion</u>
- Able to cap net demand at an arbitrary level to manage local distribution constraint
- Short-term response capability <u>could provide regulation, other ancillary services</u> adds significant value at very low impact and low cost)
- Same signals integrated commercial & institutional loads, distributed resources (backup generators)

Load Shifting Results for RTP Customers



- Winter peak load shifted by pre-heating
- Resulting new peak load at 3 AM is non-coincident with system peak at 7 AM
- Illustrates key finding that a portfolio of contract types may be optimal – i.e., we don't want to just create a new peak

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